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The Relationship of Kinetic and Kinematic Variables With Countermovement Jump Performance in Elite Team Sport Athletes

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Abstract

Background

The countermovement jump (CMJ) is widely used to assess neuromuscular performance in athletes; however, limited research has examined the integrated relationships between phase-specific kinetic and kinematic variables and performance outcomes in team-sport athletes. Therefore, the primary aim of this study was to investigate the associations between kinetic, kinematic, and performance variables during the CMJ. A secondary aim was to compare these variables between elite volleyball and basketball players.

Methods

Thirty elite male athletes participated (15 basketball players: 20.5 ± 1.3 years; 15 volleyball players: 21.4 ± 1.5 years). CMJ performance was assessed using a dual force platform system (VALD ForceDecks). Kinetic variables (mean force, mean power, peak force) were analysed separately for eccentric (ECC) and concentric (CON) phases, while kinematic variables included peak velocity in both phases. Performance variables included jump height, leg stiffness, and modified reactive strength index (RSI mod). Between-group differences were analysed using independent t-tests, and relationships between variables were assessed using Pearson correlations.

Results

Volleyball players demonstrated significantly greater ECC and CON force and power outputs, as well as higher jump height and leg stiffness ($p < 0.05–0.001$). In contrast, basketball players exhibited higher concentric peak velocity ($p = 0.002$). Correlation analyses revealed sport-specific mechanical strategies: in basketball players, jump performance was primarily associated with concentric power production, whereas in volleyball players, performance was related to a combination of concentric power, eccentric force characteristics, and movement velocity.

Conclusions

These findings indicate that athletes from different team sports adopt distinct neuromechanical strategies to achieve vertical jump performance. Volleyball players demonstrate a more force-oriented profile, whereas basketball players exhibit velocity-oriented characteristics. This differentiation has important implications for sport-specific training design and monitoring, highlighting the need for individualized force–velocity–based approaches to optimize neuromuscular performance.

INTRODUCTION

Basketball and volleyball, as team sports, are characterized by high-intensity and explosive activities such as sprinting, jumping, and rapid changes of direction, with volleyball additionally involving complex technical skills including serving, setting, and spiking (Bilici & Topateş, 2026; Zhang et al., 2025). Both sports require players to perform frequent explosive efforts to execute these actions (Pasa et al., 2019). A key distinction between the sports is that basketball is a contact sport, whereas volleyball is a non-contact sport, which contributes to differences in biomechanical and physiological demands. Nevertheless, both sports share a team-based structure and a strong reliance on neuromuscular capacities (Yin et al., 2023).

The countermovement jump (CMJ) is a valid and reliable test for assessing neuromuscular performance, particularly lower-limb explosive strength in athletic populations. Previous research has primarily focused on the validation and reliability of force-platform-derived force–time metrics (Lake et al., 2018; Ruf et al., 2024), as well as on the standardization of CMJ testing procedures (Petrigna et al., 2019). In addition, studies have examined differences in CMJ characteristics according to competitive status within the same sport, the influence of attentional focus on jump performance, and the effects of circadian variation and temperature on neuromuscular output (Cabarkapa et al., 2023; Kershner et al., 2019; Racinais et al., 2017; Martin-López et al., 2025). While these studies have substantially strengthened the methodological foundation of CMJ assessment, they have largely emphasized isolated kinetic variables, simple performance outcomes, or specific experimental manipulations, rather than integrated biomechanical analysis.

It is well established that the CMJ represents a complex biomechanical task based on eccentric (ECC)–concentric (CON) muscle activity, with each phase characterized by specific mechanical properties and functional roles. In this context, the distinct nature of the ECC and CON phases may reflect different levels of lower-limb stiffness during the countermovement and take-off (Struzik & Zawadzki, 2013). This ECC–CON interaction is commonly referred to as the stretch–shortening cycle (SSC), in which a concentric action is preceded by an eccentric movement in the opposite direction. From a mechanistic perspective, the SSC involves an initial eccentric muscle stretch, which enhances force production during the subsequent concentric phase (Bridgeman et al., 2015; McBride et al., 2008; Meylan et al., 2010; Nuzzo et al., 2008). One proposed explanation for this phenomenon is the increased formation of cross-bridges during the eccentric phase, which potentiates the following concentric contraction (Cormie et al., 2010; Sheppard et al., 2008). Considering that eccentric strength is mechanically determined by the number of active cross-bridges, Bridgeman et al. (2018) suggest that greater levels of lower-body eccentric force may result in enhanced potentiation and, consequently, improved performance in SSC activities such as the CMJ. Furthermore, eccentric contractions have been shown to generate greater force and torque outputs compared with concentric and isometric contractions. Accordingly, the eccentric component, particularly the countermovement phase, plays a central role in achieving superior jump performance within the SSC framework (Ong et al., 2016).

Despite strong theoretical and experimental evidence, research examining how eccentric and concentric phase kinetics interact with kinematic variables to determine performance outcomes such as jump

height, leg stiffness, and modified reactive strength index (RSI) remains limited. Moreover, RSI and RSI modified are frequently analysed independently of detailed phase-specific force–velocity mechanics, which restricts mechanistic interpretation of explosive performance (Petrigna et al., 2019). Additionally, most previous studies have focused on single-sport cohorts or simple between-group comparisons (e.g., starters vs. non-starters), without examining comprehensive correlational structures linking kinetic, kinematic, and performance variables within a unified analytical framework (Cabarkapa et al., 2023; Petrigna et al., 2019).

Consequently, it remains unclear whether athletes from different team sports adopt distinct mechanical strategies—such as force-dominant or velocity-dominant profiles—within the SSC framework to achieve comparable explosive performance outcomes. Furthermore, although the importance of both eccentric and concentric force production is well recognized, the relationships between phase-specific mechanical variables and performance indicators remain insufficiently understood.

Therefore, the present study addresses this gap by analysing kinetic, kinematic, and performance variables during the CMJ in elite volleyball and basketball players. By simultaneously examining phase-specific mechanical outputs and their relationships with performance indicators within and between sports, this study aims to extend current knowledge beyond descriptive or methodological approaches and contribute to a more comprehensive understanding of sport-specific neuromuscular strategies underpinning vertical jump performance.

The primary aim of this study was to examine correlations between kinetic, kinematic, and performance variables during the CMJ in elite team-sport athletes. A secondary aim was to investigate differences in these variables between elite volleyball and basketball players.

METHODS

Participants

A total of 30 elite male athletes participated in the study and were divided into two groups: 15 basketball players (age: 20.5 ± 1.3 years; height: 202.1 ± 2.9 cm; body mass: 88.0 ± 4.2 kg) and 15 volleyball players (age: 21.4 ± 1.5 years; height: 197.6 ± 3.4 cm; body mass: 89.2 ± 4.8 kg).

Inclusion criteria were: (i) age between 18 and 25 years, (ii) participation at an elite competitive level, (iii) a minimum of five training sessions per week, and (iv) participation in official competitive matches during the previous year. Participants were excluded if they had any current lower-limb injuries, pain, neurological conditions, or had sustained a lower-limb injury within the past six months.

All participants were informed about the study procedures and voluntarily provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Sport and Physical Education, University of Novi Sad (No. 52-02-27/2026-1).

The study was preregistered on the Open Science Framework (OSF), where all collected data are publicly available (https://osf.io/4fgqw; https://doi.org/10.17605/OSF.IO/4FGQW).

Study Design

This study employed a cross-sectional design to examine the relationships between kinetic, kinematic, and performance variables during the countermovement jump (CMJ) in elite male volleyball and basketball players.

Each participant performed three CMJ trials on a dual force platform system (VALD ForceDecks). The trial with the greatest jump height was selected for subsequent analysis, as it was considered to best reflect maximal neuromuscular performance.

Procedures

Participants performed countermovement jumps (CMJ) on a dual force platform system (VALD ForceDecks). As all participants were regularly engaged in training that included jumping activities, only a brief familiarization was required to ensure correct execution of the task.

Testing was conducted during the early phase of the pre-season preparatory period, when training loads were primarily focused on general physical preparation. All measurements were performed between 08:00 and 11:00 a.m. in a controlled indoor environment, with standardized conditions including temperature (20–22°C), relative humidity (40–60%), and consistent lighting. Prior to testing, participants completed a standardized 10-minute warm-up consisting of dynamic exercises (e.g., walking lunges, squat-to-heel rise, A-skips, high knees, and butt kicks) (Cabarkapa et al., 2023), followed by one set of five submaximal jumps (Ruf et al., 2024).

Each participant performed three maximal CMJ trials, with a rest interval of 30–60 seconds between attempts. The trial with the greatest jump height was selected for analysis. Participants were instructed to perform each jump with hands placed on the hips, starting from an upright standing position, followed by a self-selected countermovement (approximately 60°–90° of knee flexion) and an immediate maximal vertical jump without a pause between phases. Arm movement was restricted to reduce variability.

Strong verbal encouragement was provided throughout testing, instructing participants to exert maximal effort (Kershner et al., 2019). Trials were repeated if improper take-off or landing technique was observed. Standardization was ensured by maintaining consistent footwear, stance width, and rest intervals across all participants.

Kinetic, kinematic, and performance variables were extracted from each CMJ trial using the manufacturer’s software.

Anthropometry

Body height was measured to the nearest 0.1 cm using a Martin anthropometer (GPM, Switzerland), and body mass was measured to the nearest 0.1 kg using a calibrated balance beam scale (Avery Ltd., Model 3306 ABV).

CMJ assessment using the VALD Force Decks System

Countermovement jump (CMJ) performance was assessed using a dual force platform system (VALD ForceDecks; sampling frequency: 1,000 Hz). Jump height was calculated using the manufacturer's software (Jump Application v2.2.6 (#153), VALD Performance, Brisbane, Australia) based on the impulse–momentum method. Briefly, centre of mass velocity was derived by dividing cumulative impulse by body mass, and take-off velocity was subsequently used to estimate jump height (Lake et al., 2018).

Participants stood with both feet positioned on the platform and performed maximal-effort jumps with hands placed on the hips. Each jump was initiated from an upright standing position, followed by a self-selected countermovement (approximately 60°–90° of knee flexion) and an immediate maximal vertical jump without a pause between phases. Arm movement was restricted to reduce variability.

A rest interval of 30–60 seconds was provided between trials to ensure adequate recovery (Ruf et al., 2024). Trials were repeated if improper take-off or landing technique was observed. Strong verbal encouragement was provided throughout testing, instructing participants to exert maximal effort (Kershner et al., 2019).

Standardization was ensured by maintaining consistent footwear, stance width, and rest intervals across participants, in accordance with established protocols (Ruf et al., 2024). CMJ testing demonstrates high reliability (ICC > 0.85) and is considered a valid method for monitoring neuromuscular performance and fatigue in athletic populations (Ruf et al., 2024; Cabarkapa et al., 2023).

Each participant performed three CMJ trials, and the trial with the greatest jump height was selected for statistical analysis. Kinetic, kinematic, and performance-related variables were extracted from each trial.

Outcome measures

Kinetic and kinematic variables were obtained during CMJ testing using the VALD ForceDecks system. Based on the vertical ground reaction force (VGRF) signal, the software automatically identified the eccentric (ECC) and concentric (CON) phases of the jump. The ECC phase was defined as the period from the point at which VGRF exceeded body weight during the countermovement to the point of minimum vertical displacement of the centre of mass (approximately zero velocity), whereas the CON phase was defined as the period from the end of the ECC phase to take-off (VGRF ≈ 0). Centre of mass velocity and take-off velocity were calculated using the impulse–momentum method.

Kinetic variables (CON Mean Force (N), CON Mean Power (W), CON Peak Force (N), ECC Mean Force (N), ECC Mean Power (W), ECC Peak Force (N), ECC Peak Power (W)) were calculated separately for the ECC and CON phases. Mean force represented the average VGRF, while power was calculated as the product of force and vertical centre of mass velocity (Linthorne, 2001).

Kinematic variables included CON Peak Velocity (m/s) and ECC Peak Velocity (m/s), defined as the maximum vertical velocities during their respective phases.

Performance variables included lower-limb stiffness (N/m), calculated as the ratio of peak force to the vertical displacement of the centre of mass during the ECC phase, and the modified reactive strength index (RSI mod; m/s), defined as the ratio of jump height to time to take-off.

Statistical analysis and sample size calculation

Data are presented as mean ± standard deviation (SD). The normality of data distribution was assessed using the Shapiro–Wilk test. Although two variables deviated from normal distribution, parametric analyses were retained, as independent samples t-tests are considered robust to minor violations of normality in balanced group designs.

Differences in kinetic, kinematic, and performance variables between basketball and volleyball players were examined using independent samples t-tests. Effect sizes were interpreted alongside p-values to provide a more comprehensive understanding of practical significance. Effect sizes were calculated using Cohen's d and interpreted as negligible (≤ 0.19), small (0.20–0.49), medium (0.50–0.79), large (0.80–0.99), and very large (≥ 1.00) (Cohen, 1988). A 95% confidence interval (95% CI) was applied for all analyses, and statistical significance was set at $p < 0.05$.

Associations between kinetic, kinematic, and performance variables were assessed using Pearson's product–moment correlation coefficients. Correlation magnitudes were interpreted as trivial (r = 0.00–0.10), small (r = 0.11–0.30), moderate (r = 0.31–0.50), large (r = 0.51–0.70), very large (r = 0.71–0.90), and almost perfect (r = 0.91–1.00), according to Hopkins (2010). Given the number of correlations performed, results should be interpreted with caution due to the increased risk of Type I error.

All statistical analyses were performed using JASP (version 0.18.1). A priori power analysis was conducted using G*Power (version 3.1.9.4; Faul et al., 2009). For independent samples t-tests (two-tailed), assuming a large effect size (Cohen's d = 0.80), an alpha level of 0.05, and a total sample size of 30 participants (15 per group), the achieved statistical power was 0.87, indicating that the study was adequately powered to detect meaningful between-group differences.

Given the exploratory nature of the study and the relatively small sample size, a correlational approach was considered appropriate for identifying key associations between variables. Additionally, the selection of the best trial is consistent with previous CMJ research and reflects maximal neuromuscular performance capacity.

RESULTS

Descriptive statistics for kinetic, kinematic, and performance variables are presented in Table 1. Most variables in both groups followed a normal distribution ($p > 0.05$).

Table 1
Descriptive statistics of CMJ variables in volleyball (n = 15) and basketball (n = 15) players

	Athletes	Mean ± SD	CV	95% CI		S-W
				Upper	Lower	
Kinetic variables						
CON Mean Force (N)	Volleyball	1829.06 ± 198.16	0.108	1938.80	1719.32	0.395
	Basketball	1359.80 ± 313.32	0.230	1533.31	1186.28	0.740
CON Mean Power (W)	Volleyball	2779.66 ± 449.38	0.162	3028.52	2530.80	0.102
	Basketball	3530.80 ± 1312.50	0.372	4257.63	2803.96	0.247
CON Peak Force (N)	Volleyball	2246.06 ± 323.32	0.144	2425.11	2067.01	0.879
	Basketball	1704.60 ± 428.84	0.252	1942.08	1467.11	0.062
ECC Mean Force (N)	Volleyball	891.06 ± 80.71	0.091	935.76	846.36	0.785
	Basketball	492.93 ± 211.31	0.429	609.95	375.91	0.798
ECC Mean Power (W)	Volleyball	600.40 ± 137.21	0.229	676.38	524.41	0.807
	Basketball	387.80 ± 179.43	0.463	487.17	288.43	0.730
ECC Peak Force (N)	Volleyball	2207.73 ± 385.00	0.174	2420.94	1994.52	0.635
	Basketball	1479.53 ± 579.79	0.392	1800.61	1158.45	0.768
ECC Peak Power (W)	Volleyball	1790.06 ± 651.23	0.364	2150.70	1429.42	0.610
	Basketball	1396.33 ± 835.43	0.598	1858.98	933.68	0.885
Kinematic variables						
CON Peak Velocity (m/s)	Volleyball	2.883 ± 0.22	0.077	3.006	2.761	0.069
	Basketball	5.493 ± 2.98	0.543	7.145	3.842	0.018
ECC Peak Velocity (m/s)	Volleyball	-1.333 ± 0.26	-0.201	-1.185	-1.482	0.286
	Basketball	-1.625 ± 0.61	-0.380	-1.283	-1.967	0.939
Performance variables						
Jump height (cm)	Volleyball	41.38 ± 7.20	0.174	45.37	37.39	0.076
	Basketball	34.70 ± 5.20	0.150	37.58	31.81	0.892
Leg stiffness (N/m)	Volleyball	5718.86 ± 1629.84	0.285	6621.44	4816.28	0.422

	Athletes	Mean ± SD	CV	95% CI		S-W
				Upper	Lower	
Kinetic variables						
	Basketball	3734.84 ± 2621.49	0.702	5186.57	2283.10	0.014
RSI mod (m/s)	Volleyball	0.50 ± 0.10	0.214	0.569	0.448	0.509
	Basketball	0.45 ± 0.17	0.377	0.549	0.359	0.102

Note: SD = standard deviation; CV = coefficient of variation; 95% CI = 95% confidence interval; S–W = Shapiro–Wilk test ($p > 0.05$); CON = concentric; ECC = eccentric; RSI mod = modified reactive strength index.

Significant differences between basketball and volleyball players were observed in the majority of kinetic variables ($p \leq 0.05$–0.001), with the exception of eccentric (ECC) peak power ($p = 0.161$) (Table 2). Volleyball players demonstrated significantly higher values in both concentric (CON) and ECC force and power variables, indicating greater force production capacity.

Table 2
Differences in kinetic, kinematic, and performance variables in CMJ between volleyball (n = 15) and basketball (n = 15) players

	Athletes	Mean ± SD	Mean Difference	p	Cohen's d ES
Kinetic variables					
CON Mean Force (N)	Volleyball	1829.06 ± 198.16	469.26	0.001 ***	1.790 (very large)
	Basketball	1359.80 ± 313.32			
CON Mean Power (W)	Volleyball	2779.66 ± 449.38	-751.13	0.045 *	-0.76 (medium)
	Basketball	3530.80 ± 1312.50			
CON Peak Force (N)	Volleyball	2246.06 ± 323.32	541.46	0.001 ***	1.426 (very large)
	Basketball	1704.60 ± 428.84			
ECC Mean Force (N)	Volleyball	891.06 ± 80.71	398.13	0.001 ***	2.489 (very large)
	Basketball	492.93 ± 211.31			
ECC Mean Power (W)	Volleyball	600.40 ± 137.21	212.60	0.001 **	1.331 (very large)
	Basketball	387.80 ± 179.43			
ECC Peak Force (N)	Volleyball	2207.73 ± 385.00	728.20	0.001 ***	1.480 (very large)
	Basketball	1479.53 ± 579.79			
ECC Peak Power (W)	Volleyball	1790.06 ± 651.23	393.73	0.161	0.526 (medium)
	Basketball	1396.33 ± 835.43			
Kinematic variables					
CON Peak Velocity (m/s)	Volleyball	2.883 ± 0.22	-1.234	.002 **	-1.234 (very large)
	Basketball	5.493 ± 2.98			

	Athletes	Mean ± SD	Mean Difference	p	Cohen's d ES
Kinetic variables					
ECC Peak Velocity (m/s)	Volleyball	-1.333 ± 0.26	0.612	.105	0.612 (medium)
	Basketball	-1.625 ± 0.61			
Performance variables					
Jump height (cm)	Volleyball	41.38 ± 7.20	1.065	.007 **	1.065 (very large)
	Basketball	34.70 ± 5.20			
Leg Stiffness (N/m)	Volleyball	5718.86 ± 1629.84	0.909	.019 *	0.909 (large)
	Basketball	3734.84 ± 2621.49			
RSI mod (m/s)	Volleyball	0.50 ± 0.10	0.381	.306	0.381 (small)
	Basketball	0.45 ± 0.17			

Note: SD = standard deviation; p = statistical significance; * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ES = effect size (Cohen's d); CON = concentric; ECC = eccentric; RSI mod = modified reactive strength index.

Table 2 shows significant differences between basketball and volleyball players in most kinetic variables (p ≤ 0.05–0.001), with the exception of ECC Peak Power, where no significant difference was observed (p = 0.161).

For kinematic variables, a significant between-group difference was found in CON Peak Velocity (p ≤ 0.01), whereas no difference was observed in ECC Peak Velocity (p = 0.105).

Regarding performance variables, volleyball players demonstrated significantly greater jump height (p ≤ 0.01) and leg stiffness (p ≤ 0.05), while no significant difference was observed for RSI mod (p = 0.306).

In contrast, basketball players exhibited significantly higher CON peak velocity (p = 0.002), whereas no significant difference was observed in ECC peak velocity (p = 0.105).

Regarding performance variables, volleyball players achieved significantly greater jump height (p = 0.007) and leg stiffness (p = 0.019), while no significant difference was found for RSI mod (p = 0.306).

Correlation analyses were conducted separately for each sport to explore the relationships between mechanical variables and performance outcomes. In basketball players, limited significant associations were observed primarily between kinetic and performance variables (Table 3). CON mean power showed

a moderate positive correlation with jump height (r = 0.514, p ≤ 0.05). Both CON peak force and ECC peak force demonstrated very strong positive correlations with leg stiffness (r = 0.863 and r = 0.835, respectively; p ≤ 0.001). No significant correlations were observed between kinematic variables and performance outcomes (p > 0.05).

Table 3
Correlation in kinetic and performance variables in CMJ in basketball players

Performance variables				
r (95% CI)				
		Jump height (cm)	Leg stiffness (N/m)	RSI mod (m/s)
Kinetic variables	CON Mean Power (W)	0.514* (.003 to .813)	-0.025 (-0.530 to .494)	0.462 (-0.066 to .788)
	CON Peak Force (N)	0.189 (-0.358 to .640)	0.863*** (.630 to .954)	0.510 (-0.003 to .811)
	ECC Peak Force (N)	0.121 (-0.417 to .596)	0.835*** (.564 to .944)	0.447 (-0.085 to .781)

Note: r = Pearson correlation coefficient; 95% CI = 95% confidence interval; * p ≤ 0.05; *** p ≤ 0.001; CON = concentric; ECC = eccentric.

Table 3 presents the correlations between kinetic variables and performance variables in basketball players. Significant associations were limited and observed only in selected relationships, whereas no significant correlations were found between kinematic variables and performance outcomes (p > 0.05).

In detail, CON Mean Power showed a moderate positive correlation with jump height (r = 0.514, p ≤ 0.05), with no significant associations observed with leg stiffness or RSI mod (p > 0.05). CON Peak Force and ECC Peak Force demonstrated very strong positive correlations with leg stiffness (r = 0.863 and r = 0.835, respectively; p ≤ 0.001).

No significant correlations were observed between kinetic variables and RSI mod or between force variables and jump height beyond those reported (p > 0.05).

In volleyball players, both kinetic and kinematic variables were significantly associated with performance outcomes (Table 4). CON mean power was strongly correlated with jump height (r = 0.691, p ≤ 0.01) and RSI mod (r = 0.772, p ≤ 0.001). ECC peak power was significantly associated with multiple performance variables.

Table 4
Correlation in kinetic, kinematic, and performance variables in CMJ in volleyball players

Performance variables				
r (95% CI)				
		Jump height (cm)	Leg stiffness (N/m)	RSI mod (m/s)
Kinetic variables	CON Mean Force (N)	0.304 (-0.247 to .874)	0.656** (.216 to .874)	0.610* (.143 to .855)
	CON Mean Power (W)	0.691** (.277 to .889)	0.459 (.070 to .786)	0.772*** (.430 to .920)
	CON Peak Force (N)	0.351 (-0.197 to .732)	0.698** (.289 to .892)	0.638* (.187 to .867)
	ECC Mean Power (W)	0.448 (-0.084 to .781)	0.204 (-0.344 to .648)	0.530* (.024 to .820)
	ECC Peak Force (N)	0.395 (-0.147 to .755)	0.665** (.231 to .878)	0.621* (.160 to .860)
	ECC Peak Power (W)	0.524* (.015 to .817)	0.524* (.016 to .045)	0.730** (.347 to .904)
Kinematic variables	CON Peak Velocity (m/s)	0.962*** (.888 to .988)	-0.105 (-0.586 to .430)	0.669** (.238 to .880)
	ECC Peak Velocity (m/s)	-0.602*(-0.130 to -0.852)	-0.318 (.232 to -0.714)	-0.707**(-.306 to -0.895)

Table 4 presents the relationships between kinetic, kinematic, and performance variables in volleyball players, with multiple significant correlations observed ($p \leq 0.05–0.001$).

In detail, CON Mean Power was positively correlated with jump height ($r = 0.691$) and RSI mod ($r = 0.772$). ECC Peak Power showed significant correlations with performance variables. Both CON and ECC force variables (mean and peak) demonstrated moderate to strong correlations with leg stiffness and RSI mod ($p \leq 0.05–0.01$).

Kinematic variables exhibited particularly strong relationships with performance outcomes. CON Peak Velocity showed a very strong positive correlation with jump height ($r = 0.962$) and a strong correlation with RSI mod ($r = 0.669$). In contrast, ECC Peak Velocity showed significant negative correlations with jump height ($r = −0.602$) and RSI mod ($r = −0.707$).
Kinematic variables demonstrated particularly strong relationships. CON peak velocity showed a very strong positive correlation with jump height ($r = 0.962$, $p \leq 0.001$) and a strong correlation with RSI mod ($r = 0.669$, $p \leq 0.01$). In contrast, ECC peak velocity was negatively correlated with jump height ($r = −0.602$, $p \leq 0.05$) and RSI mod ($r = − 0.707$, $p \leq 0.01$).

DISCUSSION

This study aimed to investigate the relationships between kinetic, kinematic, and performance variables during the CMJ in elite team-sport athletes, as well as to examine differences between elite volleyball and basketball players. The main findings indicate that volleyball players demonstrated higher values in several kinetic variables, whereas basketball players exhibited higher values in selected kinematic variables. From a performance perspective, volleyball players achieved greater jump height and leg stiffness, while no significant differences were observed in RSI mod. Overall, the findings suggest that jump performance in basketball players is primarily associated with concentric (CON) power production, whereas in volleyball players it is related to a multidimensional interaction of CON power, eccentric (ECC) force characteristics, and movement velocity.

The literature directly examining kinetic and kinematic variables in volleyball and basketball athletes during CMJ performance remains limited. Previous studies have reported that volleyball players exhibit greater force and power production during both ECC and CON phases (Cabarkapa et al., 2025), which is consistent with the present findings. Similarly, Yin et al. (2023) demonstrated higher jump performance and peak force values in volleyball players. These results may reflect sport-specific neuromuscular adaptations associated with the repetitive high-intensity jumping demands of volleyball.

From a neuromechanical perspective, these differences may indicate distinct force–velocity strategies. Volleyball players appear to adopt a more force-oriented profile characterized by greater ECC loading and stiffness regulation, whereas basketball players may exhibit a velocity-oriented profile associated with rapid force application and shorter contraction times (Jiménez-Reyes et al., 2017). This interpretation is supported by the higher CON Peak Velocity observed in basketball players, as well as previous findings indicating that basketball performance is closely linked to rapid force development and movement velocity (Cabarkapa et al., 2025; Jiménez-Daza et al., 2023; Solberg et al., 2025). The dynamic and reactive nature of basketball, including frequent changes of direction and short-duration explosive actions, may further contribute to these velocity-oriented adaptations (Očić et al., 2025; Wang et al., 2024).

From a performance standpoint, the greater jump height and leg stiffness observed in volleyball players may be explained by adaptations in the muscle–tendon unit and enhanced utilization of the stretch–shortening cycle (SSC). Previous studies have consistently reported superior vertical jump performance in volleyball players (Battaglia et al., 2014; Karatrantou et al., 2019; Cabarkapa et al., 2025; Yin et al., 2023). These adaptations are likely driven by the high frequency of maximal jumping actions such as blocking and spiking, which promote the development of force production capacity and elastic energy storage.

Leg stiffness appears to play a key role in these adaptations, as it reflects the ability of the musculoskeletal system to store and reutilize elastic energy during SSC activities. Studies have shown

that repetitive loading influences tendon mechanical properties and contributes to sport-specific stiffness adaptations (Zhang et al., 2015; Laffaye et al., 2014). Accordingly, the higher leg stiffness observed in volleyball players may represent a functional adaptation that enhances jump performance through improved force transmission and energy efficiency.

In basketball players, correlation analyses indicated that performance outcomes were primarily associated with CON phase mechanical variables. Specifically, CON Mean Power was related to jump height, while both CON and ECC Peak Force showed strong associations with leg stiffness. These findings suggest that performance in basketball may depend on the effective conversion of force into movement velocity, rather than on maximal force production alone. Previous research has similarly demonstrated that CMJ performance is closely related to CON phase variables such as power, work, and displacement (Barker et al., 2018; Rice et al., 2017; Suárez-Balsera et al., 2025). The strong relationships between force variables and leg stiffness further highlight the importance of SSC efficiency and rapid force transmission.

In volleyball players, performance was associated with a broader range of mechanical variables, including both kinetic and kinematic factors. CON Mean Power and ECC Peak Power were significantly related to performance outcomes, while CON Peak Velocity demonstrated a particularly strong relationship with jump height. In contrast, ECC Peak Velocity showed negative associations with performance variables, which may reflect differences in countermovement strategies or braking mechanics. These findings suggest that volleyball players rely on a more integrated neuromechanical strategy, combining force production, movement velocity, and eccentric control.

From an applied perspective, these findings highlight the importance of sport-specific and individualized training approaches. For volleyball players, training interventions may benefit from emphasizing maximal force production, eccentric strength, and stiffness-related qualities. In contrast, basketball players may require a greater focus on velocity-based training, rapid force development, and reactive strength. Importantly, these interpretations should be considered in light of the cross-sectional design and correlational nature of the study, which precludes causal conclusions.

Overall, the present findings extend current knowledge by demonstrating that similar performance outcomes may be achieved through different neuromechanical strategies depending on sport-specific demands. This highlights the importance of integrating kinetic and kinematic analyses when evaluating CMJ performance in athletic populations.

Study Limitations

This study has several limitations that should be acknowledged. First, the relatively small sample size (n = 30) may limit the generalizability of the findings, despite adequate statistical power to detect large effects. Second, the inclusion of only elite male athletes restricts the applicability of the results to female athletes, youth populations, and non-elite performers.

Third, the cross-sectional design precludes causal inferences regarding the relationships between kinetic, kinematic, and performance variables. Additionally, the use of the best CMJ trial rather than the average of multiple trials may not fully capture intra-individual performance variability, although this approach reflects maximal neuromuscular performance capacity.

Although testing conditions were standardized, sport-specific factors such as footwear and individual movement strategies were not strictly controlled, which may have influenced force–time characteristics. Furthermore, external factors including training history, fatigue status, and neuromuscular readiness were not directly assessed.

Finally, the analysis was limited to vertical jump performance and did not include horizontal or sport-specific movement tasks, which may provide additional insight into neuromuscular performance profiles. Future research should include larger and more diverse samples, longitudinal designs, and sport-specific performance assessments, as well as more advanced analytical approaches (e.g., multivariate or regression models) to better understand the complex relationships between mechanical variables and performance outcomes.

CONCLUSION

The present findings demonstrate that sport-specific neuromuscular adaptations influence the mechanical determinants of countermovement jump performance in elite team-sport athletes. Volleyball players exhibited greater eccentric and concentric force and power outputs, whereas basketball players demonstrated higher concentric velocity characteristics, indicating distinct positions along the force–velocity continuum.

Correlation analyses further suggest that jump performance in basketball players is primarily associated with concentric power production, while in volleyball players it is determined by a more integrated interaction of concentric power, eccentric force characteristics, and movement velocity. These findings indicate that similar performance outcomes may be achieved through different neuromechanical strategies depending on sport-specific demands.

Practical Application

From an applied perspective, these findings support the use of sport-specific and individualized training approaches based on underlying force–velocity characteristics. For volleyball players, training interventions should emphasize eccentric strength development, maximal force production, and stiffness-related adaptations to enhance stretch–shortening cycle efficiency. In contrast, basketball players may benefit from velocity-oriented training strategies, including rapid force development, short ground contact times, and reactive strength exercises.

Importantly, profiling athletes based on their force–velocity characteristics may provide a valuable framework for identifying individual performance limitations and optimizing training interventions.

Integrating both kinetic and kinematic assessments within routine monitoring may further improve the precision of performance diagnostics and support evidence-based training design.

Declarations

CRediT authorship contribution statement

Musab Cagin: Writing – review & editing, Writing – original draft, Conceptualization, Methodology, Formal analysis.

Marko Joksimović: Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization, Project administration.

Mila Vukadinović-Jurišić: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization, Visualization, Validation, Investigation.

Nebahat Eler: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

Jelena Obradović: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization, Visualization, Validation, Investigation.

Matej Plevnik: Writing – review & editing, Writing – original draft, Methodology, Conceptualization, Supervision.

Ethics approval and consent to participate

All participants were informed about the study procedures and voluntarily provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Sport and Physical Education, University of Novi Sad (No. 52-02-27/2026-1).

The study was preregistered on the Open Science Framework (OSF), where all collected data are publicly available (https://osf.io/4fgqw; https://doi.org/10.17605/OSF.IO/4FGQW).

Consent for publication

Not applicable.

Availability of data and materials

The data and materials that support the findings of this study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare no competing interests.

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Authors' contributions

Musab Cagin: Writing – review & editing, Writing – original draft, Conceptualization, Methodology, Formal analysis.

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Generative AI statement

During the preparation of this work the authors used ChatGPT (OpenAI, GPT-Auto) to support language refinement of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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